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(54) **DYNAMIC CONTROL OF POWER SWITCHING BIPOLAR JUNCTION TRANSISTOR**

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G05B 24/02 (2006.01)

(52) **U.S. Cl.**
USPC **315/224**; 315/307; 315/308

(58) **Field of Classification Search**
USPC 315/224, 297, 307, 308, 258; 323/349
See application file for complete search history.

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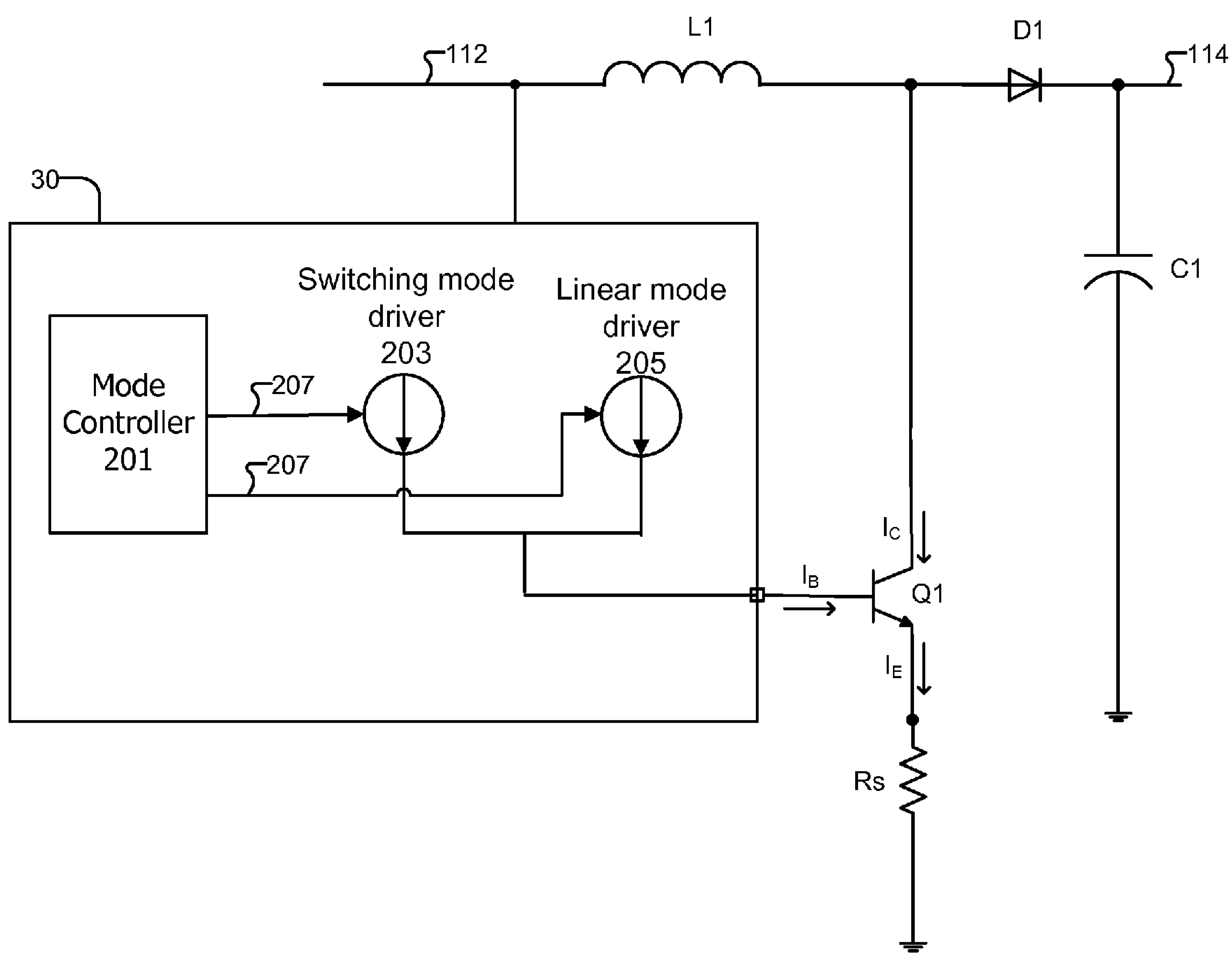
(57) **ABSTRACT**

The embodiments disclosed herein describe the dynamic control of a switching power converter between different operation modes of the switching power converter. In one embodiment, the operation modes of the switching power converter include a switching mode and a linear mode. The switching power converter may be included in a LED lamp system according to one embodiment.

15 Claims, 6 Drawing Sheets



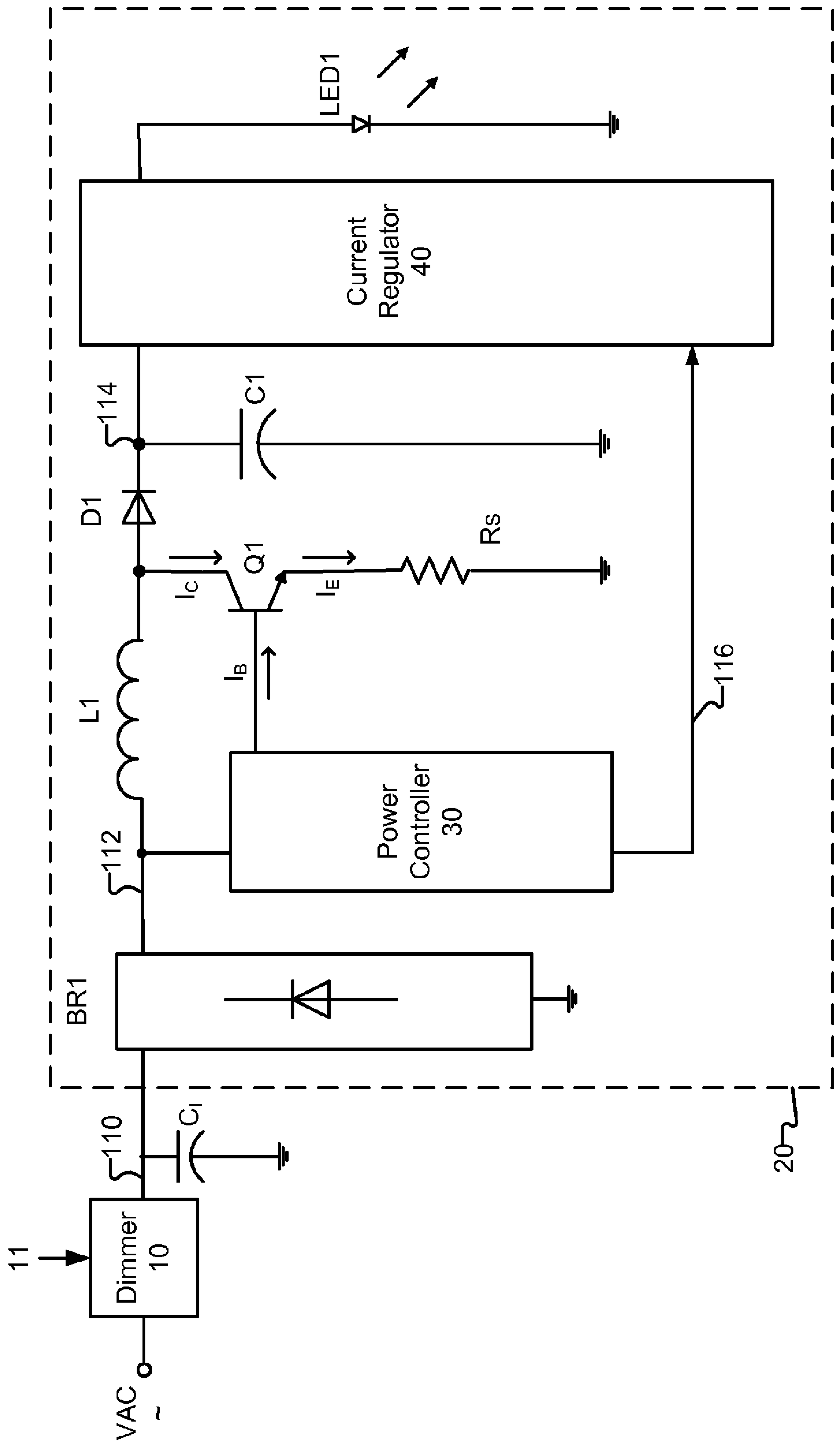

VAC
11
Dimmer
10
110
CI
20
BR1
112
Power
Controller
30
L1
IB
IC
Q1
IE
RS
D1
114
C1
116
Current
Regulator
40
LED1

FIG. 1

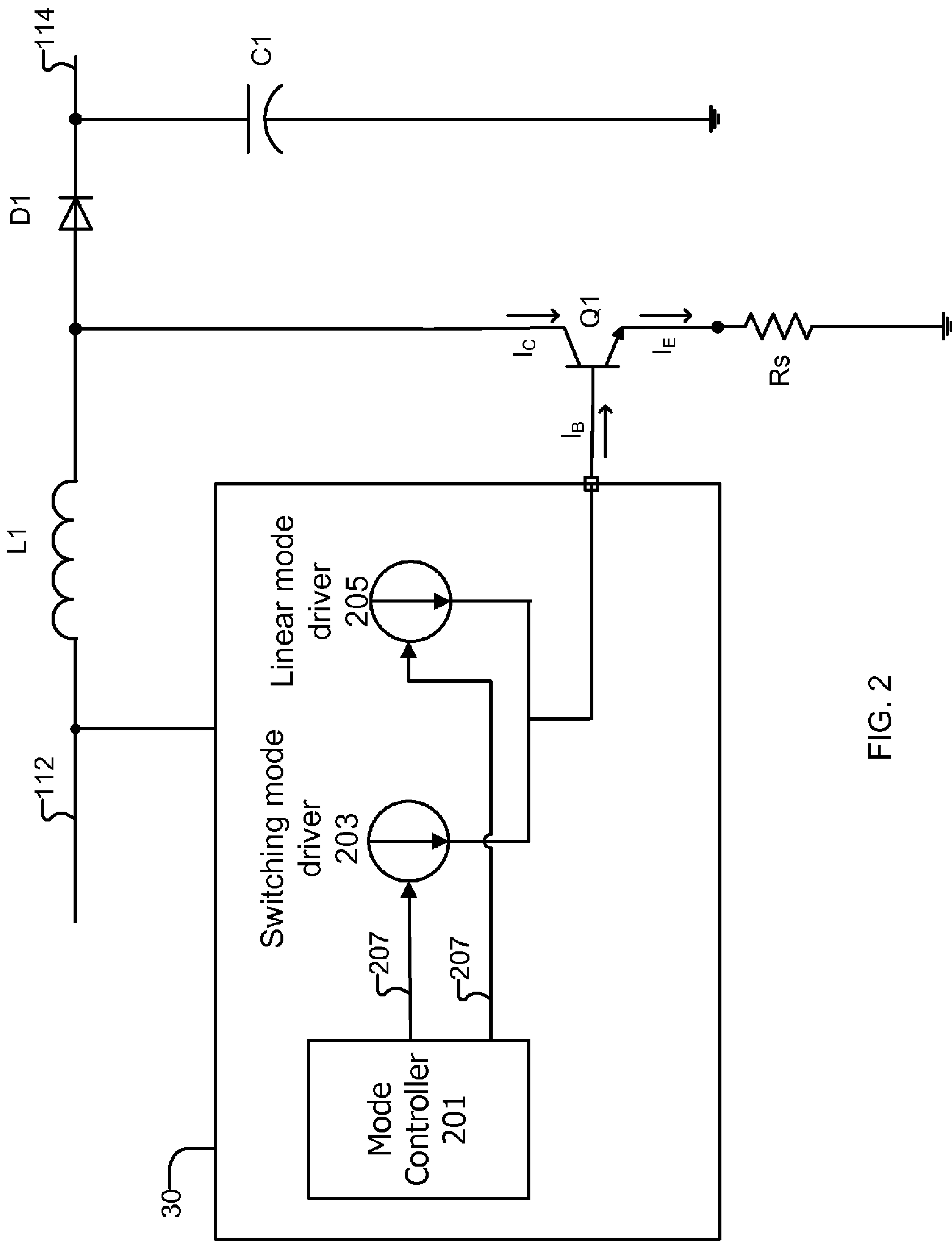

114
C1
D1
L1
112
Q1
I_C
I_E
I_B
Rs
Linear mode driver 205
Switching mode driver 203
207
207
Mode Controller 201
30

FIG. 2

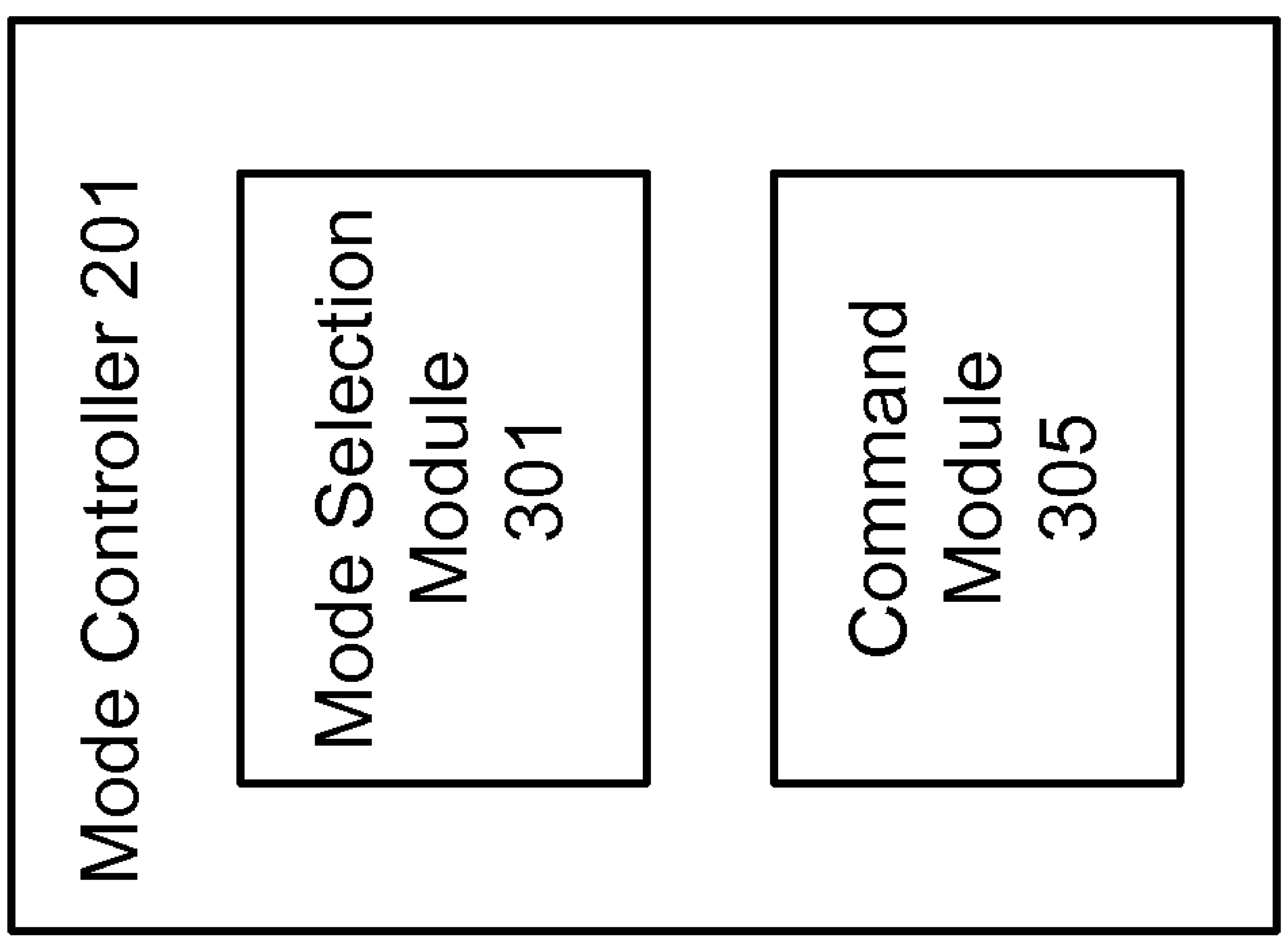

Mode Controller 201
Mode Selection Module 301
Command Module 305

FIG. 3

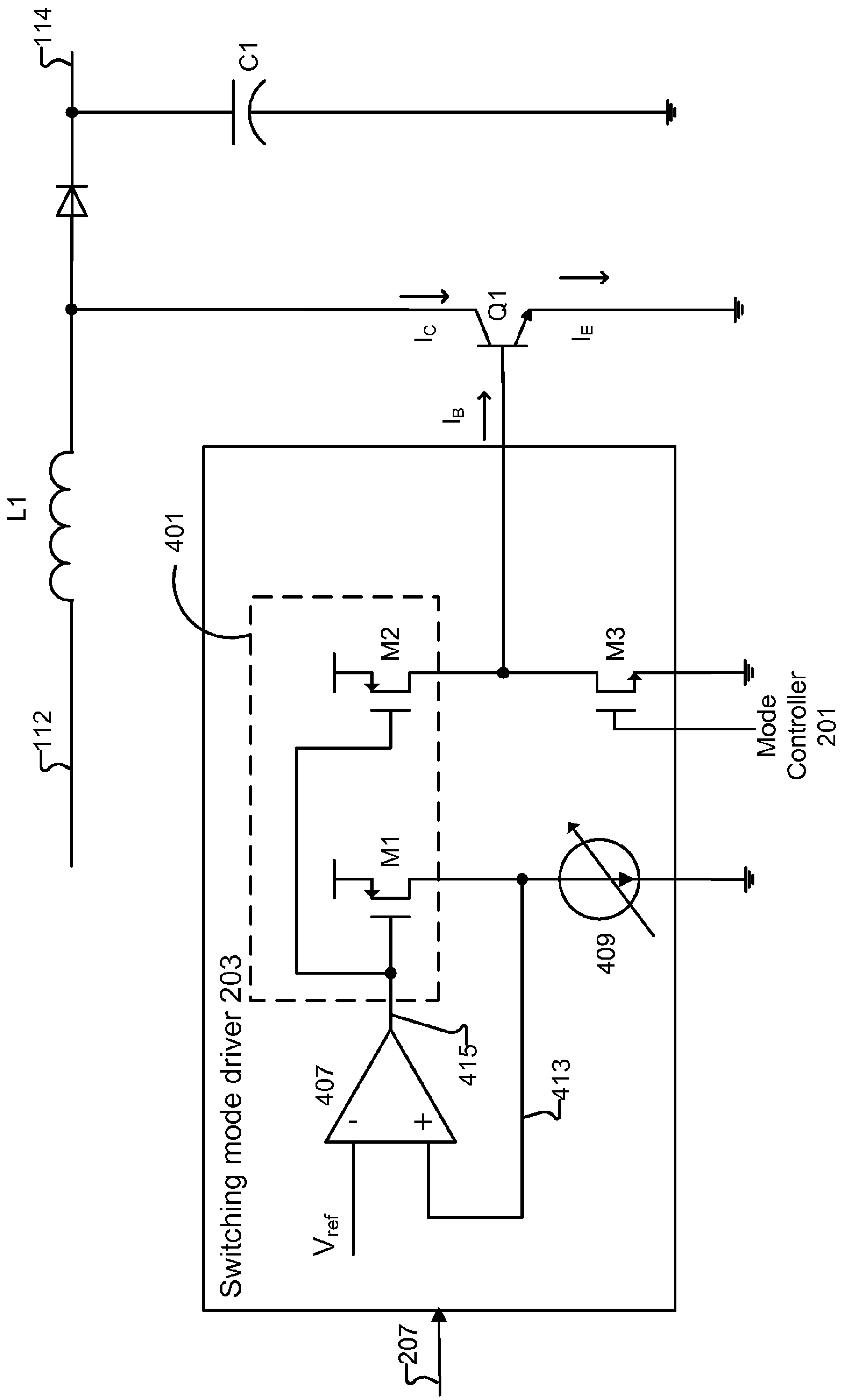

114
C1
L1
112
401
Q1
I_C
I_E
I_B
M2
M3
M1
Mode
Controller
201
409
407
415
413
V_{ref}
Switching mode driver 203
207

FIG. 4

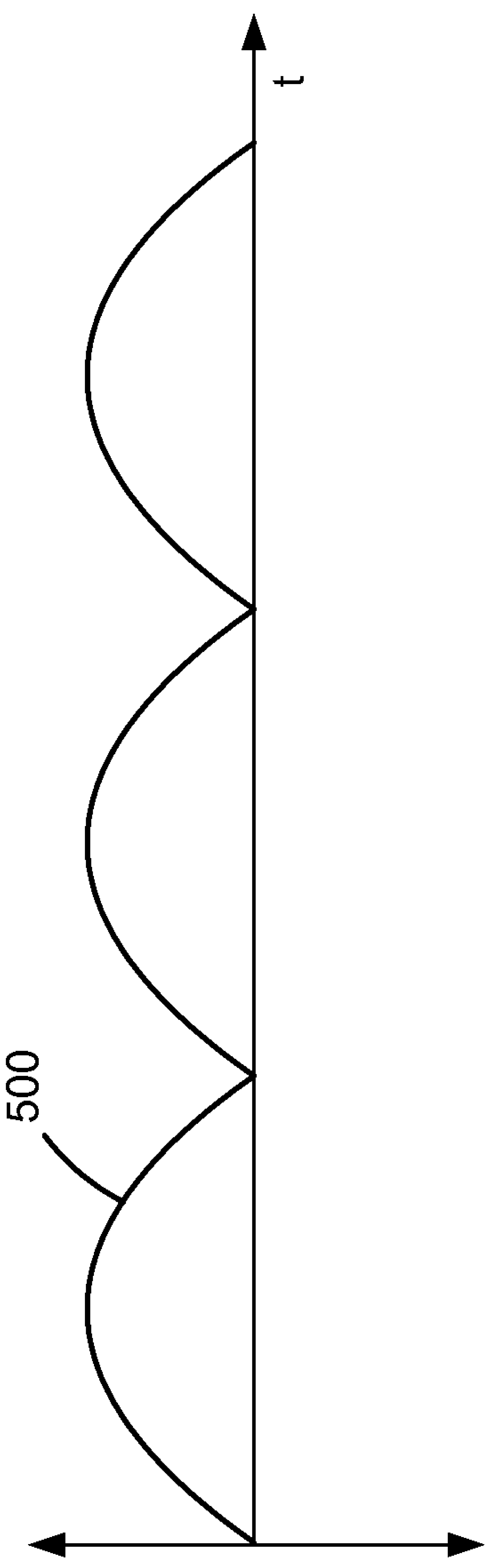


FIG. 5A

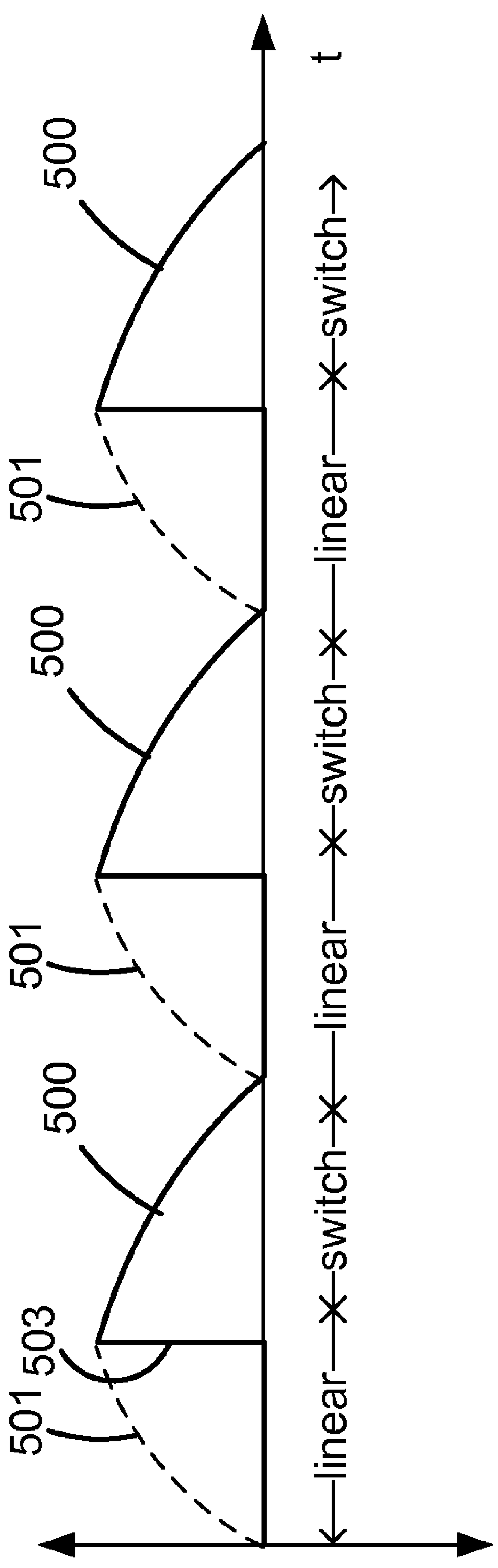


FIG. 5B

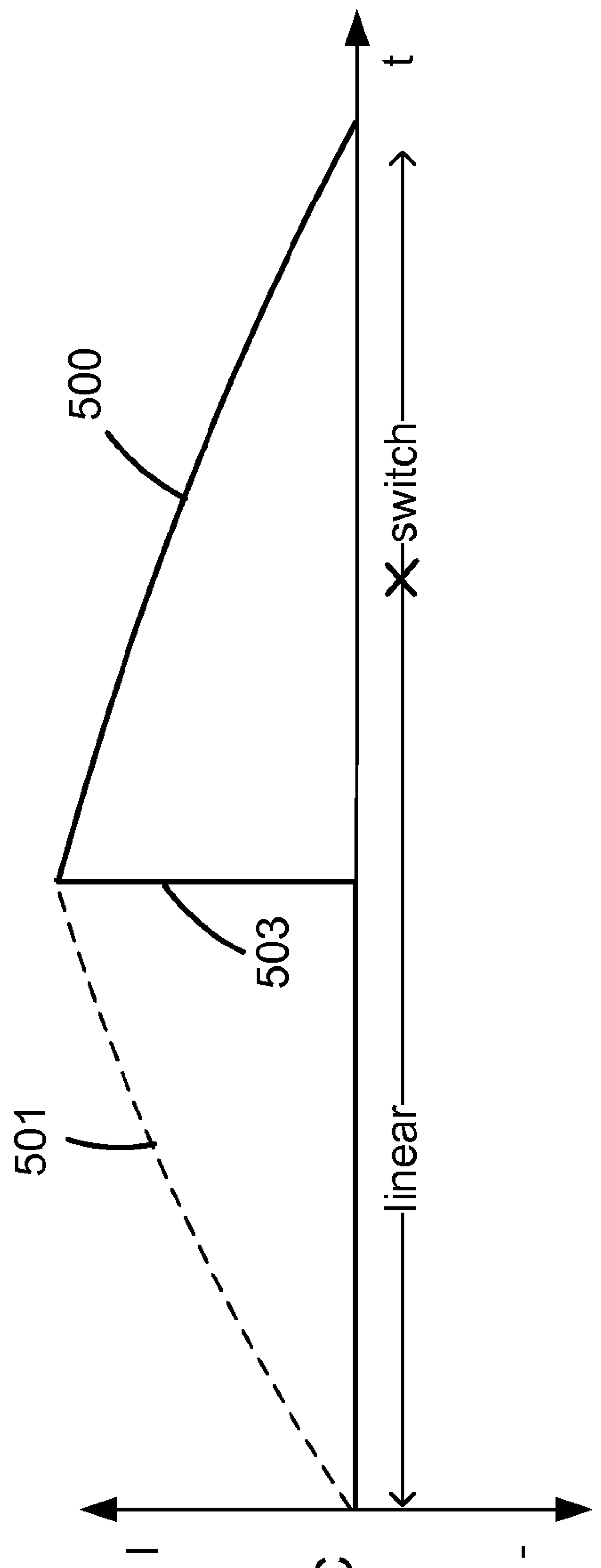

500
501
503
t
switch
linear
+ I
-

FIG. 5C

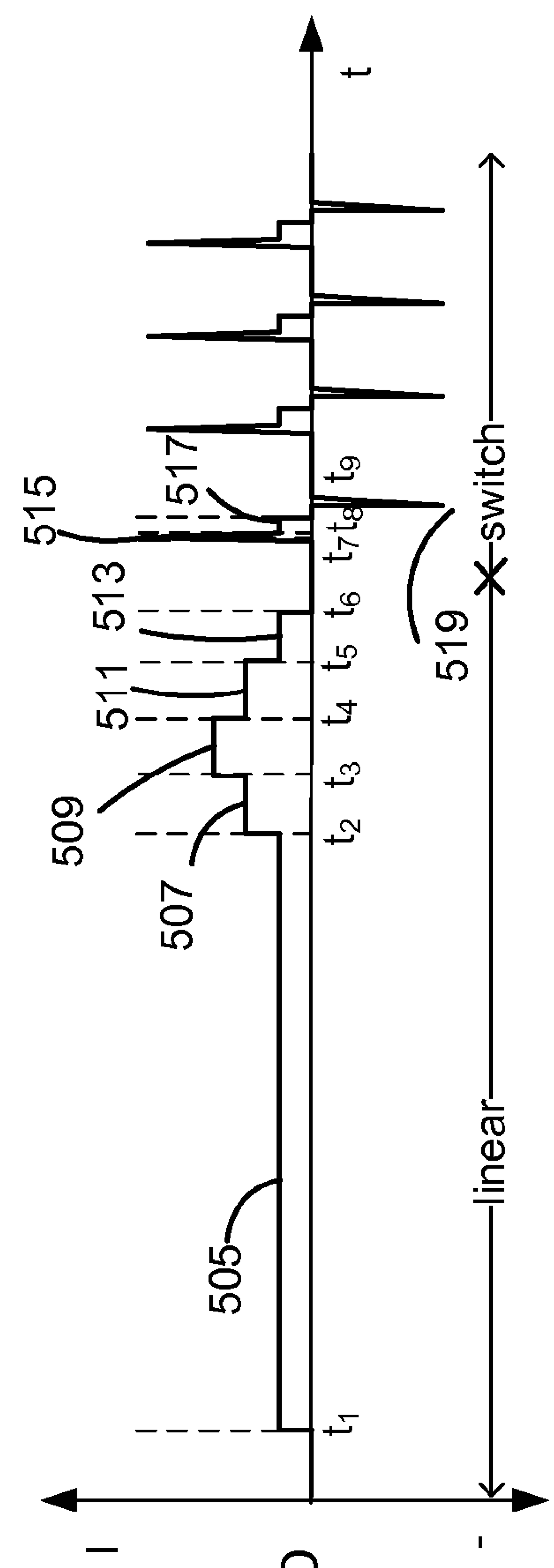

505
507
509
511
513
515
517
519
t
t_1
t_2
t_3
t_4
t_5
t_6
t_7
t_8
t_9
switch
linear
+ I
-

FIG. 5D

DYNAMIC CONTROL OF POWER SWITCHING BIPOLAR JUNCTION TRANSISTOR

BACKGROUND

1. Field of Technology

Embodiments disclosed herein relate generally to a switching power converter and more specifically to the dynamic driving of the switching transistor in a switching power converter.

2. Description of the Related Arts

Retrofit LED lamp systems are often designed and manufactured to operate with a conventional LED lamp used with a conventional phase-cut dimmer switch. The majority of the leading edge phase-cut dimmer switches adjust the lamp input voltage using a TRIAC circuit. A TRIAC is a bidirectional device that conducts current in either direction when it is triggered (i.e., turned on). Once triggered, the TRIAC continues to conduct until the current drops below a certain threshold, called a holding current threshold. For the internal timing of a TRIAC dimmer to function properly and for reducing the power consumption, current must be drawn from the dimmer at certain times at certain levels. Unfortunately, conventional LED lamps require multiple current control paths to draw current from the dimmer switch in a manner that allows the internal circuitry of the dimmer to function properly and minimize the power losses.

SUMMARY OF THE INVENTION

The embodiments disclosed herein describe the dynamic control of a switching power converter between different operation modes of the switching power converter. In one embodiment, the operation modes of the switching power converter include a switching mode and a linear mode. The switching power converter may be included in a LED lamp system according to one embodiment.

A bipolar junction transistor (BJT) may be used as the switching device in the switching power converter. A power controller controls whether the BJT operates in the cutoff mode, saturation mode, or active mode thereby causing the BJT to operate as an open circuit, a closed circuit, or a constant current sink based on the mode of operation. In one embodiment, the switching power converter operates in a "switching mode" when the BJT functions as a switch. Generally, the BJT operates as a switch when the controller toggles the BJT between the saturation mode and the cutoff mode. During the switching mode, the switching power converter provides direct current (DC) output voltage to a current regulator. The current regulator regulates current through LEDs of the LED lamp system to control the light output intensity of the LED lamp system.

In one embodiment, the switching power converter is operated in the "linear mode" when the BJT is operated in the active mode. When in the active mode, the BJT functions as a current sink. During the linear mode of the switching power converter, current from a dimmer switch included in the LED lamp system is drawn to the BJT to allow the internal circuitry of the dimmer switch to function properly. Furthermore, capacitors between the dimmer switch and the LED lamp in the LED lamp system are discharged because the current in the switching power converter is directed through the BJT functioning as a current sink. By discharging the capacitors, the switching power converter allows the internal circuitry of the dimmer switch to function properly. Furthermore, to overcome the dimmer parasitic oscillation, an adequate current can be drawn immediately after the dimmer phase-cut appears by operating the BJT as a current sink.

The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings and specification. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the embodiments disclosed herein can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

FIG. **1** illustrates a LED lamp system according to one embodiment.

FIG. **2** illustrates a detailed view of a power controller according to one embodiment.

FIG. **3** illustrates a detailed view of a mode controller according to one embodiment.

FIG. **4** illustrates a detailed view of a switching mode driver according to one embodiment.

FIGS. **5**A, **5**B, **5**C, and **5**D illustrate lamp input voltage waveforms and current waveforms of a drive transistor according to one embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

The Figures (FIG.) and the following description relate to various embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles discussed herein.

Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict various embodiments for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Embodiments disclosed herein describe a method of a power controller that dynamically controls the operation of a switching power converter between a switching mode and a linear mode. In one embodiment, a BJT is used as the switching device (i.e., the drive transistor) in the switching power converter of an LED lamp system. A BJT operates in different modes of operation including the cutoff mode, saturation mode, or active mode. A BJT is configured to function as an open circuit, a closed circuit, or a constant current sink based the mode of operation of the BJT.

In one embodiment, the power controller controls the BJT to toggle between the saturation mode and the cutoff mode resulting in the BJT functioning as a switch. When the BJT operates as a switch, the switching power converter is operating in a "switching mode" according to one embodiment. During the switching mode, the switching power converter delivers electrical power to a load such as a string of LEDs. The controller further controls the BJT to operate in the active mode resulting in the BJT functioning as an adjustable current sink. When the BJT operates as a current sink, the switching power converter operates in a "linear mode" according to one embodiment. During the linear mode, current is drawn to the BJT thereby drawing current from a dimmer switch of the LED lamp system that sets the desired light output intensity of a LED lamp. Drawing current from the dimmer switch allows the internal circuitry of the dimmer switch to function properly. Furthermore, during the linear mode the BJT discharges capacitors formed between the LED lamp and the dimmer switch. Discharging the input capacitors allows the internal circuitry of the dimmer switch to function properly.

FIG. **1** illustrates an LED lamp system including a dimmer switch **10** and a LED lamp **20**. Capacitances C_I are formed between the dimmer switch **10** and the LED lamp **20**. In one embodiment, dimmer switch **10** is a conventional dimmer switch and receives a dimming input signal **11**, which is used to set the target light output intensity of LED lamp **20**. Dimmer switch **10** receives an AC input voltage signal VAC and adjusts the V-RMS value of the lamp input voltage **110** in response to dimming input signal **11**. In other words, control of light intensity of LED lamp **20** by the dimmer switch **10** is achieved by adjusting the V-RMS value of the lamp input voltage **110** that is applied to LED lamp **20**. Dimming input signal **11** can either be provided manually (via a knob or slider switch, not shown herein) or via an automated lighting control system (not shown herein).

One example of a dimmer switch is described in U.S. Pat. No. 7,936,132 which is incorporated by reference in its entirety. In one embodiment, dimmer switch **10** employs phase angle switching of the lamp input voltage **110** to adjust the lamp input voltage by using a TRIAC circuit. As previously described above, a TRIAC is a bidirectional device that can conduct current in either direction when it is triggered. For the internal timing of a TRIAC dimmer to function properly, current must be drawn from the dimmer **10** at certain times. In one embodiment, the LED lamp **20** is configured to draw current from the dimmer **10** in a manner that allows the internal circuitry of the dimmer **10** to function properly.

The LED lamp **20** includes a bridge rectifier BR**1**, an inductor L**1**, a diode D**1**, a capacitor C**1**, a drive transistor Q**1**, a sense resistor Rs, a power controller **30**, a current regulator **40**, and a light emitting diode LED**1**. Generally speaking, the LED lamp **20** employs a boost type switching AC-DC power converter comprised of inductor L**1**, diode D**1**, capacitor C**1**, and drive transistor Q**1**, using the drive transistor Q**1** as the switching device driven by a dynamic switch drive signal. Drive transistor Q**1** is a BJT in one embodiment. Note that in other embodiments other power converter topologies may be used for the power converter such as the flyback topology.

Specifically, the bridge rectifier BR**1** receives the phase-angle adjusted AC voltage **110** and generates a rectified input voltage **112**. The power controller **30** receives the rectified input voltage **112** and controls the base current I_B to the drive transistor Q1 coupled to the power controller **30**. Generally, the power controller **30** controls the boost converter shown in FIG. **1** that performs AC-DC voltage conversion.

The current regulator **40** receives the DC output voltage **114** from the power converter. The current regulator **40** also receives one or more control signals **116** from the power controller **30** and regulates current through the light emitting diode LED**1** under the control of the control signals **116**. Control signals **116** may include, for example, an indication of the phase-cut in the rectified input signal **112**. Current regulator **40** may employ pulse-width-modulation (PWM) or constant current control to achieve the target light output intensity for the light emitting diode LED**1**. In one embodiment, current regulator **40** is a collection of components that uses a flyback topology to regulate current through the light emitting diode LED**1**.

In one embodiment, the power controller **30** controls whether the power converter is operating in the switching mode or in the linear mode based on the mode of operation of the drive transistor Q**1**. As described previously, the power converter operates in the switching mode when the drive transistor Q**1** is operated in the saturation mode and the power converter operates in the linear mode when the drive transistor Q**1** is operated in the active mode. In one embodiment, the mode of operation of the drive transistor Q**1** is controlled by the power controller **30** by selecting whether a switching mode driver **203** or a linear mode driver **205** drives the drive transistor Q1 as shown in FIG. **2**.

FIG. **2** illustrates a detailed view of the power controller **30** according to one embodiment. The power controller **30** comprises a mode controller **201**, a switching mode driver **203**, and a linear mode driver **205**. The mode controller **201** selects whether the switching mode driver **203** or the linear mode driver **205** drives the base current I_B of the drive transistor Q**1** by sending a selection signal **207** to the switching mode driver **203** or the linear mode driver **205**. If the mode controller **201** selects the switching mode driver **203** to drive the drive transistor Q**1**, the switching mode driver **203** supplies a range of current magnitude to the base of the drive transistor Q**1** causing the drive transistor Q**1** to operate in the saturation mode where the collector-emitter voltage is nearly zero.

As described previously, the drive transistor Q**1** operates as a fully turned-on switch when in the saturation mode. The switching mode driver **203** supplies a large enough current to the base of the drive transistor Q1 to put the drive transistor Q1 deep into the saturation mode. Otherwise, a large collector-emitter voltage occurs resulting in efficiency loss of the switching power converter. In one embodiment, the range of current magnitude supplied by the switching mode driver **203** ranges from 7 mA to 93 mA. Other current ranges may be employed in different embodiments. The switching mode driver **203** may also supply current at discrete values within the aforementioned current range with step sizes ranging from 1 mA to 3 mA in one embodiment. Different step sizes may be used for different LED lamp systems of various power levels.

When the drive transistor Q**1** is operated in the saturation mode (i.e., the drive transistor Q**1** is turned on), current flows from the rectified input voltage **112** through the inductor L**1** to the drive transistor Q**1** to ground. The current flowing through the inductor L**1** causes the inductor L**1** to store energy. When the drive transistor Q**1** is operated in the cutoff mode (i.e., the drive transistor Q**1** is turned off), the energy stored in the inductor L**1** flows through the diode D**1** to the current regulator **40** that regulates current through the light emitting diode LED**1**.

If the mode controller **201** selects the linear mode driver **205** to drive the drive transistor Q**1**, the linear mode driver **205** supplies a range of current magnitude to the base of the drive transistor Q**1** to operate the drive transistor Q**1** in the active mode. In one embodiment, the range of current magnitude supplied by the linear mode driver **205** to the base of the drive transistor Q**1** is lower than the current range supplied by the switching mode driver **203**. The range of current magnitude supplied by the linear mode driver **205** ranges from 0.4 mA to 28 mA according to one embodiment. The linear mode driver **205** may also supply current at discrete values within the aforementioned current range with step sizes that are smaller than the step sizes provided by the switching mode driver **203**. In one embodiment, the step size of current provided by the linear mode driver **205** ranges from 0.2 mA to 0.8 mA. The smaller step sizes may be used to finely control the drive transistor Q**1** in the active mode without operating the drive transistor Q**1** outside of its safe operating region. The current provided to the drive transistor Q**1** may be increased during the linear mode to put the drive transistor deep in the active mode such that the collector-emitter voltage is maintained at a high voltage (e.g., roughly 500 V). The current supplied to the drive transistor Q**1** may be increased until the unsafe operating limits of the drive transistor Q**1** are reached.

When the drive transistor Q**1** is in the active mode, the drive transistor Q**1** operates as a current sink. Accordingly, current from the dimmer **10** is drawn to the drive transistor Q**1** when the power converter is operated in the linear mode to allow the internal circuitry of the dimmer **10** to function properly. Furthermore, charges stored in capacitors C_I formed between the dimmer **10** and the LED lamp **20** flows to the drive transistor Q**1** thereby discharging the capacitors C_I. Discharging the capacitors C_I allows the internal circuitry of the dimmer **10** to function properly.

If the base current I_B supplied by the linear mode driver **205** is too high, the collector current I_C of the drive transistor Q**1** may rise high enough (i.e., to a threshold level) that the unsafe operating area of the drive transistor Q**1** is approached. In response, the mode controller **201** may instruct the switching mode driver **203** to drive current to the drive transistor Q**1** to put the drive transistor Q**1** into the saturation mode or to lower the magnitude of current supplied to the base of the drive transistor Q**1**. Thus, the mode controller **201** accommodates the conduction and thermal limits of the drive transistor Q**1** by providing a large range of adjustability of the current that may be supplied to the base of the drive transistor Q**1**.

Referring now to FIG. **3**, one embodiment of a detailed view of the mode controller **201** is illustrated. In one embodiment, the mode controller **201** comprises a mode selection module **301** and a command module **305**. As is known in the art, the term "module" refers to computer program logic or logic circuits utilized to provide the specified functionality. Thus, a module can be implemented in hardware, firmware, and/or software.

In one embodiment, the mode selection module **301** determines whether to operate the LED lamp **20** in the switching mode or the linear mode. The mode selection module **301** determines the mode of operation of the LED lamp **20** based on the rectified input voltage **112**. The phase and magnitude of the rectified input voltage **112** indicates the dimmer output status. If the dimmer output indicates a high voltage, the high voltage signifies that the dimmer switch **10** is turned-on and the mode selection module **301** operates the power converter in the switching mode (i.e., the drive transistor Q**1** is operated in the saturation mode). Conversely, if the dimmer output indicates a low voltage, the low voltage signifies that the dimmer switch **10** turned-off and the mode selection module **301** operates the power converter in the linear mode (i.e., the drive transistor Q**1** is operated in the active mode). The mode selection module **301** communicates the selected mode to the command module **305**.

In one embodiment, the command module **305** receives the mode selected by the mode selection module **301** and generates the selection signal **207** that instructs either the switching mode driver **203** or the linear mode driver **205** to drive the drive transistor Q**1**. In one embodiment, the selection signal **207** additionally indicates the magnitude of the current that the switching mode driver **203** or the linear mode driver **205** generates to drive the drive transistor Q**1**. In one embodiment, the magnitude of the base current is determined by the required collector current I_C. For example, if the required collector current I_C is 200 mA and the drive transistor Q**1** gain is 20, then the base drive current is set higher than 10 mA during the switching mode. Conversely, while in the linear mode, the base current is set to 10 mA.

FIG. **4** illustrates a detailed view of the switching mode driver **203** according to one embodiment. The switching mode driver **203** comprises a current mirror **401**, an operational amplifier **407**, an adjustable current source **409**, and a metal-oxide-semiconductor field-effect transistor M**3** (mosfet) according to one embodiment. The operational amplifier **407** turns on or turns off the current mirror **401** that generates the current used to drive the base of the drive transistor Q**1**. The operational amplifier **407** compares a voltage reference V_{ref} with a voltage **413** at the drain of mosfet M**1** included in the current mirror **401**. When the voltage **413** input to the operational amplifier **407** is greater than the voltage reference V_{ref}, the operational amplifier **407** outputs a signal **415** to the gate of the P-type mosfet M**1** and the gate of the P-type mosfet M**2** that are included in the current mirror **401**. The signal **415** sent by the operational amplifier **407** turns on mosfet M**1** and mosfet M**2** included in the current mirror **401** causing the generation of current that is supplied to the base the drive transistor Q**1**. The gate of mosfet M**3** is coupled to the mode controller **201**. The mode controller **201** turns off mosfet M**3** which is a N-type mosfet that is used to quickly discharge the drive transistor Q**1** when the drive transistor Q**1** is turned off as will be further described below.

Note that although only two mosfets are shown in the current mirror **401**, any number of mosfets may be used to adjust the magnitude of the current supplied to the base of the drive transistor Q**1**. The switching mode driver **203** adjusts the magnitude of the current provided to the base of the drive transistor Q**1** based on the ratio of the current mirror **401** (i.e., the number of mosfets included in the current mirror **401**) and the magnitude of the current generated by the adjustable current source **409**. The current generated by the adjustable current source **409** is the reference current of the current mirror **401**. The ratio of the current mirror **401** determines the amplification factor of the reference current set by the adjustable current source **409**. In other words, the ratio of the current mirror **401** and the magnitude of the reference current determine the magnitude of the current that is provided to the base of the drive transistor Q**1**.

Furthermore, the ratio of the current mirror **401** determines the step size of current magnitude that is provided to the base of the drive transistor Q**1** since the current mirror **401** amplifies the reference current set by the adjustable current source **409**. Thus, if the reference current is adjusted from a first reference current to a larger second reference current, the ratio of the current mirror **401** determines the larger current magnitude supplied to the base of the drive transistor Q**1** resulting from the amplification of the second reference current. Furthermore, the number of current mirrors used by the switching mode driver **203** determines whether the step size is fine or granular since each current mirror may be associated with a different amplification factor.

Note that a similar circuit may be used for the linear mode driver **205** and is omitted for ease of description. However, the ratio of the current mirror and the reference current used by the linear mode driver **205** may be different than the switching mode driver **203** to implement the different current range and different current steps sizes of the linear mode driver **205** compared to the switching mode driver **203**.

When the input voltage set by the adjustable current source **409** is less than the voltage reference V_{ref}, the operational amplifier **407** sends a signal **415** that turns off the P-type mosfet M**1** and P-type mosfet M**2** that are included in the current mirror **401** and turns on N-type mosfet M**3**. Because the base of the drive transistor Q**1** is no longer receiving current, the drive transistor Q**1** turns off. N-type mosfet M**3** is turned on by the mode controller **201** when the drive transistor Q**1** turns off to provide a discharge path to quickly turn off the drive transistor Q**1**.

Referring to FIG. **5**A, the AC voltage input into the dimmer switch **10** is illustrated. If the dimmer switch **10** is set to maximum light intensity, the AC voltage signal **500** from the input voltage source is unaffected by the dimmer switch **10**. Thus, the lamp input voltage **110** is similar to the AC voltage signal **500** shown in FIG. **5**A. FIG. **5**B illustrates lamp input voltage **110** with a slight dimming effect as the dimmer switch **10** eliminates partial sections **501** of the AC voltage signal inputted into the dimmer switch **10**. As shown in FIG. **5**B, the LED lamp system cycles between the linear mode and the switching mode previously described above. During the linear mode, the power controller **30** operates the drive transistor Q**1** in its active mode by precisely controlling the base current I_B to the drive transistor Q**1**. During the switching mode, the power controller **30** operates the drive transistor Q**1** in its saturation mode by switching the drive transistor Q**1** on and off.

The linear modes and switching modes do not line up exactly with the phase cut **503**. Instead, the linear mode extends past the phase cut **503** for a small amount of time until the power controller **30** switches to the switching mode. Due the sudden change in the rectified input voltage **112** caused by the phase cut **503**, adjusting the base current I_B in response to the phase cut **503** would be difficult if the power controller **30** operates with closed loop feedback (closed loop systems are slower). However, because the power controller **30** operates as an open loop, it can quickly adjust the base current I_B to account for any sudden changes in the rectified input voltage **112**, such as the phase cut **503**.

FIG. **5**C illustrates a detailed view of rectified input voltage **112** to the LED lamp **20** with the slight dimming effect and FIG. **5**D illustrates a detailed view of the current supplied to the base of the drive transistor Q**1** during the linear mode and the switching mode. Particularly, FIG. **5**D illustrates how the power controller **30** adjusts the base current of the drive transistor Q**1** to cause the drive transistor Q**1** to operate in either the active mode or the saturation mode which is the bases of the LED lamp **20** operating in either the linear mode or the switching mode. Note that the current magnitudes illustrated in FIG. **5**D are not to scale. As shown in FIG. **5**D, the magnitude, duration, and step size of the current provided to the base of the drive transistor Q**1** vary significantly during the linear mode and the switching mode however they may not be vary significantly in other embodiments.

During the linear mode, the varying current magnitude supplied to the base of the drive transistor Q**1** as shown in FIG. **5**D causes the drive transistor Q**1** to operate in the active mode. As previously described above, during the active mode, the drive transistor Q**1** functions as a current sink. Thus, during the linear mode shown in FIG. **5**D, current is drawn from the dimmer switch **10** to the drive transistor Q**1** to allow the internal circuitry of the dimmer switch **10** to function properly.

At time t_1, current supplied to the base of the drive transistor Q**1** is increased to a first current magnitude **505** thereby placing the switching power converter in the linear mode because the drive transistor Q**1** is operated in the active mode. The first current magnitude **505** is provided to the drive transistor Q**1** to operate the drive transistor Q**1** in the active mode until time t_2. After the phase cut **503**, the current supplied to the drive transistor Q**1** is calibrated to determine the current to supply to the drive transistor Q**1** in the linear mode of the next AC cycle. Generally, from time t_2 to time t_6, different value levels of current magnitude are provided to the drive transistor Q**1** to identify which current magnitude will be used to drive the drive transistor Q**1** during the linear mode of the next AC cycle. Note that the current magnitudes provided from time t_2 to time t_6 cause the drive transistor Q**1** to continue operating in the active mode.

At time t_2, the current supplied to the base of the BJT switch **209** is increased to a second current magnitude **507** which keeps the drive transistor Q**1** in the active mode. At time t_3, the current supplied to the base of the drive transistor Q**1** is increased to a third current magnitude **509** which may correspond to the peak current supplied to the drive transistor Q**1** during the linear mode. The current supplied to the base of the drive transistor Q**1** may increased until the safe operating limits of the drive transistor Q**1** are approached in order to put the drive transistor Q**1** deep in the active mode. At time t_4, the current supplied to the base of the drive transistor Q**1** is decreased to a fourth current magnitude **511** and at time t_5 the current supplied to the base of the drive transistor Q**1** is further decreased to a fifth current magnitude **513**. The LED lamp **20** is still in the linear mode as the current supplied to the base of the drive transistor Q**1** is adjusted from the fourth current magnitude **511** to the fifth current magnitude **513**. Again, the current supplied to the base of the drive transistor Q**1** is adjusted in order to calibrate the current that will be supplied to the drive transistor Q**1** during the linear mode of the next AC cycle. At time t_6, current is not supplied to the base of the drive transistor Q**1**.

During the switching mode, the varying current magnitudes supplied to the base of the current supplied to the base of the drive transistor Q**1** as shown in FIG. **5**D causes the drive transistor Q**1** to operate in the saturation mode. As previously described above, during the saturation mode, the drive transistor Q**1** functions as a switch. Thus, during the switching mode shown in FIG. **5**D, a DC output voltage **114** is provided to the current regulator **40** to power LED **1**.

At time t_7, the current supplied to the base of the drive transistor Q**1** is increased to a sixth current magnitude **515** which corresponds to the peak current supplied to the base of the drive transistor Q**1** during the switching mode. The sixth current magnitude **515** supplied to the base of the drive transistor Q**1** causes the drive transistor Q**1** to operate in the saturation mode thereby causing the LED lamp **20** to operate in the switching mode. At time t_8, the current supplied to the base of the current supplied to the base of the drive transistor Q**1** is decreased to a seventh current magnitude **517** which keeps the drive transistor Q**1** in the saturation mode. At time t_9, the current supplied to the base of the drive transistor Q**1** is decreased to an eighth current magnitude **519** causing the drive transistor Q**1** to operate in the cutoff mode (i.e., off). Although the drive transistor Q**1** is off, the LED lamp **20** is still operating in the switching mode. The current magnitude supplied to the drive transistor Q**1** is further adjusted during the switching mode of the power converter as shown in FIG. **5**D to supply power to LED**1**.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for controlling the operation modes of power converters. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the embodiments discussed herein are not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A switching power converter comprising:

a magnetic component coupled to an input voltage and to an output of the switching power converter;

a bipolar junction transistor (BJT) switch coupled to the magnetic component, current through the magnetic component being generated while the BJT switch is operating in a saturation mode and not being generated while the BJT switch is operating in a cutoff mode; and

a controller configured to generate a control signal to operate the BJT switch in the saturation mode, the cutoff mode, or an active mode;

wherein the switching power converter operates in a switching mode responsive to the BJT switch continuously switching operation between the saturation mode and the cutoff mode, the switching power converter delivering power to the output of the switching power converter during the switching mode;

wherein the switching power converter operates in a linear mode responsive to the BJT switch operating in the active mode, wherein the BJT switch is configured to draw current from a dimmer switch coupled to the switching power converter during the linear mode.

2. The switching power converter of claim **1**, wherein input capacitors between the switching power converter and the dimmer switch are discharged via the BJT switch during the linear mode.

3. The switching power converter of claim **1**, wherein the switching power converter is incorporated into a light emitting diode lamp.

4. The switching power converter of claim **1**, further comprising:

a switching mode driver configured to generate a first range of current magnitude that drives a base terminal of the BJT switch responsive to receiving the control signal from the controller, the first range of current magnitude causing the BJT switch to operate in the saturation mode; and

a linear mode driver configured to generate a second range of current magnitude that drives the base terminal of the BJT switch responsive to receiving the control signal from the controller, the second range of current magnitude causing the BJT switch to operate in the active mode.

5. The switching power converter of claim **4**, wherein a lower end of the first range of current magnitude is greater than at least a lower end of the second range of current magnitude, and a higher end of the first range of current magnitude is greater than at least a higher end of the second range of current magnitude.

6. The switching power converter of claim **4**, wherein the switching mode driver is further configured to increase the current delivered to the base terminal of the BJT switch from a first current magnitude to a second current magnitude during the switching mode to keep the BJT switch in the saturation mode and wherein the linear mode driver is further configured to maintain the current delivered to the base terminal of the BJT switch at a third current magnitude to keep the BJT switch in the active mode.

7. The switching power converter of claim **6**, wherein the linear mode driver is further configured to increase the current delivered to the base terminal of the BJT switch from the third current magnitude to a fourth current magnitude during the linear mode to determine a current magnitude to deliver to the base terminal of the BJT switch during the linear mode in a next AC cycle to keep the BJT switch in the active mode.

8. The switching power converter of claim **7**, wherein a current step size from the first current magnitude to the second current magnitude during the switching mode is larger than the a current step size from the third current magnitude to the fourth current magnitude during the linear mode.

9. In a controller, a method of controlling a switching power converter, the switching power converter including a magnetic component coupled to an input voltage and to an output of the switching power converter and a bipolar junction transistor (BJT) switch coupled to the magnetic component, current through the magnetic component being generated while the BJT switch is operating in a saturation mode and not being generated while the BJT switch is operating in a cutoff mode, the method comprising:

generating a control signal to operate the BJT switch in the saturation mode, the cutoff mode, or an active mode;

operating the switching power converter in a switching mode with the BJT switch continuously switching operation between the saturation mode and the cutoff mode, the switching power converter delivering power to the output of the switching power converter during the switching mode; and

operating the switching power converter in a linear mode with the BJT switch operating in the active mode;

wherein the BJT switch is configured to draw current from a dimmer switch coupled to the switching power converter during the linear mode.

10. The method of claim **9**, wherein input capacitors between the switching power converter and the dimmer switch are discharged via the BJT switch during the linear mode.

11. The method of claim **9**, wherein the control signal controls a switching mode driver to generate a first range of current magnitude that drives a base terminal of the BJT switch to operate the BJT switch in the saturation mode responsive to the switching mode driver receiving the control signal and wherein the control signal controls a linear mode driver to generate a second range of current magnitude that drives the base terminal of the BJT switch to operate the BJT switch in the active mode responsive to the linear mode driver receiving the control signal.

12. The method of claim **11**, wherein a lower end of the first range of current magnitude is greater than at least a lower end of the second range of current magnitude, and a higher end of the first range of current magnitude is greater than at least a higher end of the second range of current magnitude.

13. The method of claim **11**, wherein the control signal controls the switching mode driver to increase the current delivered to the base terminal of the BJT switch from a first current magnitude to a second current magnitude during the switching mode to keep the BJT switch in the saturation mode and wherein the control signal controls the linear mode driver to maintain the current delivered to the base terminal of the BJT switch at a third current magnitude to keep the BJT switch in the active mode.

14. The method of claim **13**, wherein the control signal further controls the linear mode driver to increase the current delivered to the base terminal of the BJT switch from the third current magnitude to a fourth magnitude during the linear mode to determine a current magnitude to deliver to the base terminal of the BJT switch during the linear mode in a next AC cycle to keep the BJT switch in the active mode.

15. The method of claim **14**, wherein a current step size from the first current magnitude to the second current magnitude during the switching mode is larger than a current step size from the third current magnitude to the fourth current magnitude during the linear mode.

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